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SADAŠNJOST I BUDUĆNOST

Urednik
Božo Krstajić

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Sadržaj: *Gde god se koristi električna energija postoje mogućnosti za povećanje efikasnosti njenog korišćenja. U većini slučajeva, primenjene mere energetske efikasnosti otplaćuju se kroz niže račune (troškova). Vodovodni sistemi su veliki potrošači električne energije. Investicije u povećanje energetske efikasnosti ovih sistema ne samo da ima ekonomsku dimenziju, već takođe ima i pozitivan efekat na okolinu jer sa smanjenom potrošnjom fosilnih goriva smanjuje se i emisija štetnih gasova. Ovaj rad predlaže suvremeni način povećanje energetske efikasnosti vodovodnih sistema sa poboljšanjem faktora snage pumpnih postrojenja i analizu njegove dobrobiti.*

Abstract: *Wherever the energy is used, there are the opportunities for increasing its effectiveness. In most cases, the energy efficiency solutions are repaid through the lower energy bills (expenses). There is large electrical energy consumption in the water supply systems. Investments in the increasing of their energy efficiency will not only have an economic dimension, but also they could have large positive effect on environment because along with reduced consumption of fossil fuels, there will be reduction of the greenhouse gases. This paper proposes one modern method for increasing energy efficiency of water supply pump stations and an analysis of the potential benefits of this method.*

1. INTRODUCTION

Water supply systems are large energy consumers. These systems consume electric power at each of the stages of the water production and supply chain: starting from pumping the water to the water treatment plant, along the water treatment process and during distribution of the water via the water supply network. Energy is lost due to various reasons: inefficient pump stations, poor system design, installation and/or maintenance, old pipes with high network losses, bottlenecks in the supply network as well as inefficient operation strategies of the various supply facilities [1].

The major portion of the total energy spendings of the water supply systems are the cost for electricity in the process of the water pumping. Changes of the operation mode and manner of pumping can be quite effective. Some methods that could reduce electricity consumption in the process of pumping the water have already been investigated, such as, optimization of the pumps operation mode depending on the needs and the peak and off-peak electricity prices, starting of the motors in the right sequence for adequate propulsion of the motor pumps and/or reduction of the maximum power, reactive power management by applying appropriate capacitor banks [1], etc.

This paper deals with the method for increasing the energy efficiency of a typical water supply system by improvements of the reactive power management of the existing power supply system. Special attention is paid to the

analysis of the expected economic advantages which the proposed method could bring to the water supply company.

2. ANALYSIS OF THE EXISTING WATER SUPPLY SYSTEM

The high amount of the electricity bills, large number of dissatisfied consumers and poor quality of the water supply services, put the water supply company PC "Plavaja" from Radovich, into a inevitable position to look for immediate, quick and proven technical and especially economical proposals for overcoming the above mentioned drawbacks and improving the energy efficiency of its operations.

To select suitable methods for increasing the energy efficiency in this particular water supply system, analysis and research of the existing operations and costs initially had to be done. The existing energy supply concept was investigated and the so-called reference annual electricity consumption was determined. Analysis of the type, suitability and age of the major water supply equipment and its advantages and disadvantages was also done.

Based on these information, several methods for optimization of the operations, including savings and benefits were analysed and officially proposed to the company's management, giving them an opportunity to decide which of them are technically and economically affordable.

The investigated water supply system operates through mixed gravitational/pumping mode, where gravitational

system is used from three existing water catchments: “Ambari”, “Stara kaptaza” and “Filter stanica”, on one side, and water pumping system from the two pumping systems: “Industrija” and “Raklish”, on the other side. Both pumping systems are connected with drawn pool which is filled with water from ten existing water wells [2].

It was proven that the water consumption is a time-variable with the amounts that significantly varies annually, monthly, daily and even hourly. These variations are generally implied from climate condition changes, the work of the major industrial plants, the number of inhabitants, the standard of the population, etc. According to the analyzed data, larger water consumption occurs during the summer period compared to the winter period. The average daily consumption during winter was 89 l/s, while in the summer the water consumption goes as high as 122 l/s [2]. The difference indicates a possibility of introducing two separate operational modes for the water supply system, the summer operational mode and the winter operational mode. This was the firstly suggested activity among the others for increasing the energy efficiency of the whole water supply system [2].

the needs for water pumping was significantly reduced. In total, for the whole year the achieved cost reduction was about 67.5%. The reduced energy consumption was primarily due to the disconnection (*turning off*) of the pump stations during the winter period as obsolete and improvements in the operational mode of the whole company by implementing zoning water supply system.

Although the implementation of these changes provided a significant reduction in the electricity costs, due to some additional and mainly technical disadvantages in the existing electrical system supply, the company still have continued to pay relatively high costs, especially for excessive utilization of the reactive power taken from the electric power supply grid. The crucial approach to solve this was to improve the power factor of the pumping systems, i.e. to decrease the amount of reactive power taken from the grid and replace it with locally generated one. This task required proper reactive power compensation, i.e. installation of adequately designed and properly installed reactive power compensation [3].

3. REACTIVE POWER COMPENSATION

In the most cases the electrical devices, despite taking the active power from the electric power grid, they are also take the reactive power as well. If this reactive power is not produced locally at the place where it is spent, in order for the device to operate normally, needed reactive power must be taken from the supplying electric power grid. This implies additional money payments i.e. additional operational costs. There are multiple ways to generate reactive power, but for this kind of local usage, appropriately dimensioned capacitor banks are commonly used [4]. From technical viewpoint, if the requested reactive power is less than 15% of the total installed capacity of the supply transformer, a fixed value of compensation is more suitable. Above the 15% level, it is advisable to install an automatically-controlled bank of capacitors. As can be seen later in the paper, our system is on the edge having about 16% of the installed transformer's capacity, therefore, the major decision point was financial one – the cheaper solution was preferred, therefore a capacitor banks with fixed compensation value ware selected.

Figure 2 shows power comparison scheme for an electric motor that uses reactive power from the electric power network and an electric motor that uses reactive power generated from a local capacitor banks. It is obviously what kind of benefits for energy efficiency improvements could provides local reactive power compensation. Observing Figure 2-a leads to a conclusion that an inductive load having a low power factor (*the electric motor*) requires generators and transmission/distribution substations to provide needed reactive power. If a bank of capacitors is added next to the load (Figure 2-b), there will be no reactive power flow from the electricity grid towards the load (*the electric motor*) [3].

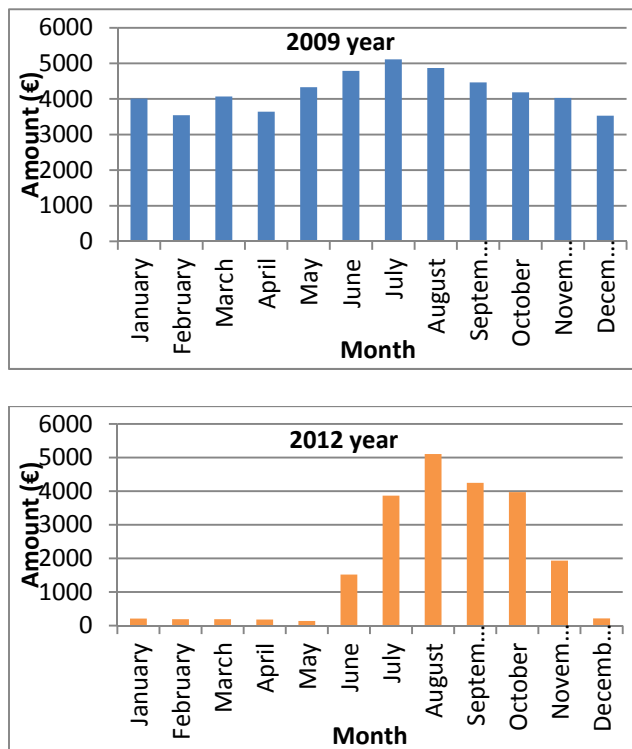


Fig. 1: Electricity cost for consumed power paid for 2009 and 2012 year.

Based on the collected data from the electricity bills, as well as the amount of the consumed power per month, a significant decrease of the cost has been achieved. Figure 1 shows the comparison between monthly electricity bills paid before and after the implementation of these two seasonal operation modes for the water supply system, i.e. in 2009 and in 2012. One can notice significant drop in the total electricity consumption and electricity bills, especially in the winter period, where the needed water amount could be provided only by means of gravitational method, therefore,

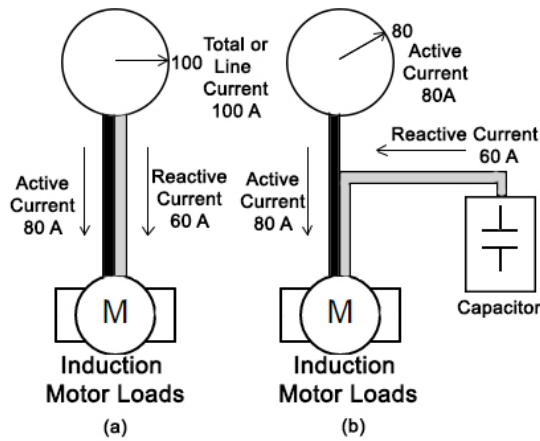


Fig. 2: Power supply of electric motor without (a), and with (b) local reactive power compensation.

The investigated water supply system uses two types of electric AC motors which use reactive power directly from the electric power grid. Accordingly, with the application of adequate reactive power compensation generated locally by installed capacitor banks, additional increase of the energy efficiency of the whole system could be expected. In such case, the installed capacitor banks, could provide only a part of the requested reactive power, leading to a reasonable increased value of the power factor at least to a level of 0.96. This is because only a power systems that have power factor less than 0.95 are required to pay additional cost for taking the excessive reactive power from the electric power grid.

4. DESIGN AND CALCULATION OF THE REACTIVE POWER COMPENSATOR BANKS

Calculation of the required reactive energy for compensation and selection of the compensation type are two most important steps to achieve optimal cost-benefit of the proposed activity. The existing pumping systems consists of two pumping stations with three electric motors with installed capacity of 45 [kW], and two electric motors with installed capacity of 22 [kW] (Figure 3). Both pumping stations are located next to each other and adjoint to the supplying transformer substation. Respectively, the best solution for installation of capacitor banks, was that they should be located within the transformer substation and that they should operate in parallel with both existing pumping stations.

At full power, the total load amounts $3 \cdot 45 \text{ kW} + 2 \cdot 22 \text{ kW} = 179 \text{ [kW]}$. Table 1 shows the power factors, $\cos\phi$ at rated load for each electric motor which is used in the analysed pumping system. The existing power factors for both motors from 0.89 and 0.88, should be improved and increased at least to the minimal accepted value of 0.96 by locally generated reactive power. The amount of added reactive power should be calculated using well-known formula:

$$Q_c = Q_1 - Q_2 = P \cdot (\tan\phi_1 - \tan\phi_2) [\text{VAr}]$$

where Q_1 , and Q_2 , are the values of the reactive power needed to achieve existing, undesired low power factors and new improved and desired power factors. The values of the angles between the voltage and the current before and after the correction (*improvement*) of the power factor $\cos\phi$ for the both pumping stations for calculating the amount of the reactive power that needs to be generated from the capacitor bank (Q_c), are given in Table 1, respectively.

Table 1: Power factors and angles between the voltages and the currents.

Power factor ($\cos\phi$)		Angle between voltage and current (ϕ)
electric motor I	0.89	27°
electric motor II	0.88	28°
after correction	0.96	16°

Thus, the calculated amount of reactive power that should be additionally provided by the capacitor banks is 4.9 [VAr], and 12.9 [VAr] for electric motor I and for electric motor II, respectively. Therefore, full reactive power compensation for the whole electricity supply system (*both pumping stations and all five motors*) to the desired value of $\cos\phi=0.96$, a total amount of 40.5 [kVAr] reactive power is required.

Because of the power supply stability and continuous load factor, as well as the short distance between the pumping stations and the the supply transformer substation (*less than 10 meters*), the central compensation system is proposed. The capacitor banks should be installed at the same busbar as the pumping stations next to the power transformer, to provide enough reactive power for the whole installation. Using this layout, one could eliminate tariff penalties for excessive consumption of reactive power from the grid on one side, and on the other, the supply transformer will be further relieved from unnecessary load, increase its efficiency and prolong its operational life [3]. The main disadvantage of central compensation mode is the fact that the reactive current generated by the capacitor banks still would flow in the supply cables towards the pumping stations, generating additional power losses. However, due to the very short distance between the power transformer and the pumping stations, increase of the power losses should be insignificant.

As mentioned in the introduction of this paper, the total amount of reactive power for full reactive power compensation in this particular case amounts at 16%, because the total installed capacity of the power transformer is 250 kVA. Having into consideration the investment cost and the expected benefits, we expect that for this particular system, fixed compensation system should be more appropriate because of small performance requirements and low control complexity. The use of automatically-controlled capacitor banks is not necessary and would be too costly for this system [3].

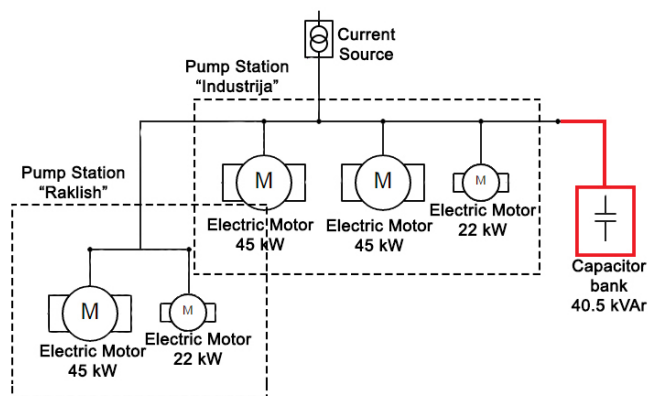


Fig. 3: PC "Plavaja" pump stations with central fixed reactive power compensation system.

Figure 4 shows the correlation between the price for reactive power compensation equipment for each $[kVAr]$ installed, provided from large amount of producers of such type of equipment [5]. According to this data, one could estimate the necessary cost for installation of capacity banks with exactly known amount of reactive power.

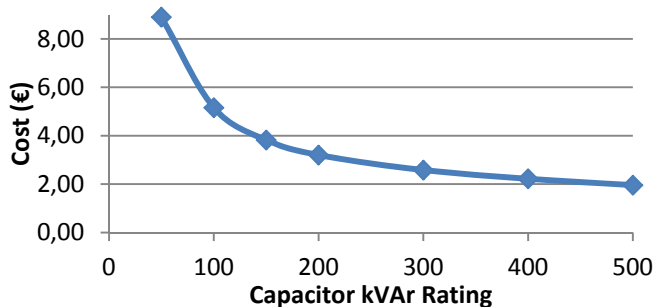


Fig. 4: Average cost per $[kVAr]$ for compensation equipment from different manufacturers [5]

According to Figure 4, for the required reactive power of 40,5 $[kVAr]$, the cost of the needed equipment for the installed reactive power of about 50 $[kVAr]$ should be considered, which means that the unit price of 8.89 € per $[kVAr]$ reactive power should be used.

5. COST-EFFECTIVENESS OF THE PROPOSED METHOD

Optimized management of reactive power brings economic and technical advantages. The impact of this method on the quality of the electricity (*flickers, harmonics, etc.*), and possible negative repercussions back into the electricity grid have to be further investigated, however only in case of acceptance of the proposed method by the company's management.

As for the economic benefits, the total financial resources spent for the reactive power for the period between 2008 and 2013, as presented in Figure 5, were estimates at 1,559€, i.e. an average of 259.83€ per year, while the total investment for purchase of the proposed compensation equipment and the

realization of this improvement method is estimated at 326.5€.

These numbers are only one indicator of the significant profitability of this investment, which according to the data given above, the full investment in the capacitor banks would be paid off for approximately 1 year and 3 months. If a comparative analysis of the cost paid for the reactive power is made in terms of total electricity cost paid per year, one can noted that only with the implementation of the proposed measure the enterprise would save at least 1.7% from the existing electricity bills.

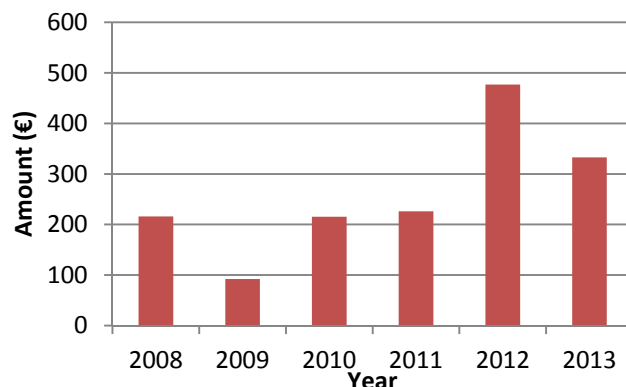


Fig. 5: Cost paid for taken reactive power from power grid for the period between 2008 and 2013 year.

6. CONCLUSION

In this paper the economic benefit of the power factor compensation method is given. The proposed method that allows elimination of the excessive reactive power from the electric grid taken by pumping motors is given. For reactive power compensation utilizing capacitor banks is proposed enabling additional cost reduction that the company pays for electricity. Additional advantage of the proposed measure is the fact that it has very low investment costs for its implementation and realization, and provides energy efficiency improvements and energy savings with very short-term payback.

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